GENERALIZED VIBRATIONAL INTENSITY AND SELECTION RULES (GVISR)

V. Paar

Institute "Rudjer Bošković", Zagreb

A quantum-mechanical description of a many-body system can be generally given in terms of elementary excitations and their couplings[1]. Pronounced fermion- and boson-types of elementary excitations in spherical and transitional nuclei are associated with valence-shell particles and low-frequency vibrations, respectively[2–22]. The leading-order particle-vibration coupling (PVC) is linear in boson amplitude and fermion current. Therefore, a nuclear system of coupled elementary excitations is in some respect analogous to dynamical systems in quantum electrodynamics, quantum fluids, and solid state physics.

In the cluster-vibration model (CVM)[3-22], the division in two types of nuclear elementary excitations is performed phenomenologically. We concentrate on describing nuclei with few (n) particles or holes (cluster) in the proton or neutron valence shell or subshell (i.e., closed-shell or subshell ±1, ±2, ±3, ±4, etc. protons or neutrons). Cluster appear as explicit fermion degrees of freedom. All other shell-model degrees of freedom are assumed to be immersed in the vibrational degree of freedom of the basic vibrator nucleus. Since quadrupole vibrations are of primary importance for most nuclear low-lying spectra, we will restrict our further discussion to these spectra. The importance of clusters appears especially for $n = 3$ (Alaga model). In fact, the Pauli principle in the valence shell is thus accounted for. Two important physical correlations are automatically included:

(i) the explicit appearance of broken and promoted pairs

(ii) the anharmonic structure of the neighbouring doubly-even nuclei.

The effects of the Pauli principle within the cluster, combined with the PVC, turn out to be significant for the description and understanding of nuclear properties[5,9,11].

The energies and wave functions of the coupled CVM system are obtained by straightforward diagonalization of the

CVM Hamiltonian in the basis built from the states $|(j_1,...,j_n) J,N R;I\rangle$, which are antisymmetrized in n single particles (holes) of the cluster and symmetrized in N quadrupole phonons. J and τ represent the angular momentum of the cluster and possible additional quantum numbers, respectively, and R is the angular momentum of N-phonon states. Using these wave functions, we can calculate the matrix elements of the electromagnetic operators, transfer reactions, etc., i.e., provide a description of different nuclear properties on an equal footing both odd- and even-A nuclei[3-21].

The diagonalization results of the CVM represent a summation of all digrams up to infinite order that in the intermediate states have the basic states included in the configuration space.

The following question arises naturally: Is it possible to find an easily manageable class of dominant diagrams which dominate certain physical properties? If so, this leads to a straightforward extraction of the basic physical properties from the CVM picture. The main qualitative pattern of such classes can then be expressed in terms of asymptotic intensity and selection rules.

For the CVM, involving a simple explicit form of interactions and operators, the answer is partly affirmative, and the corresponding asymptotic rules are called GVISR. The guide line of GVISR is a tendency towards cancellation of vertex and self-energy corrections.

Then, we have the following situations:

- There is only the lowest-order plus coherent induced polarisation, thus GVISR resemble the effect of the weak coupling pattern.
- Besides the lowest-order process there is incoherent polarization and/or additional response processes (not of the vertex correction or self-energy type), which compete with the lowest-order process and thus essentially modify the "weak-coupling" pattern. In this way GVISR resemble some features of the "strong-coupling" pattern.
- In between there is a possibility of gradually interchan-

ging or even dissolving the GVISR classification.

In the CVM, for nontrivial cases with clusters containing more than one single particle, the important role of the Pauli principle is also reflected, in both the starting point, GVISR classification (zeroth-order), and in possible systematic signs, interference, reduction or even vanishing of some matrix elements.

The following question arises: GVISR are based on the discussion of a finite number of low-order diagrams, although they are not based on weak coupling. Although we can justify this step (Ward intensity)[22] in the asymptotic limit, in the actual shell-model situation of nondegenerate levels, the radius of convergence decreases and there often appears the "crossing" of levels. Obviously, the perturbation expansion starts to diverge for physically interesting cases. (Though, the radius of convergence may be appreciably enhanced by increasing the distance of the particular intermediate levels from the initial or final state. For certain properties, this can be done without basically affecting qualitative and even quantitative results[9-18]). However, the simple GVISR classification is still useful, because it reproduces the qualitative and sometimes even semiquantitative features of the diagonalization results. (In the CVM, we have the exact result.). In fact, GVISR were born out of realizing the appearance of some systematic pattern in the results of diagonalization. Later on, it became obvious that the behaviour of some leading terms can be blamed for these systematic features.

On the other hand, it is appearing to understand the results as a consequence of low-order structures. In fact, our CVM Hamiltonian is approximate; generally, the Hamiltonian is

$$H_{(true)} = H_{(model)} + H_{(rest)} .$$

By diagonalizing the $H_{(model)}$ in a definite basis, all contributions up to infinite-order perturbation terms are included in the results. If the model is not too far from reality, (i.e., $H_{(true)}$) in leading order we really do not expect too important competititons of terms coming from $H_{(rest)}$. However, particular higher-order terms from $H_{(model)}$ (100^{th} order, for example), and and therefore also the corresponding features which might arise from them, are expected to be more influenced and burdened by $H_{(rest)}$.

Concluding, we stress that the physics involved in GVISR is only that of CVM. The essence of GVISR is to provide a simple straightforward extraction of the basic physical properties, selection and intensity rules, within CVM. Thus, it enables one, in a pedestrian way, to obtain easily a qualitative description of nuclear properties. The basic idea of GVISR is illustrated in fig. 1. In many cases, further simplification of

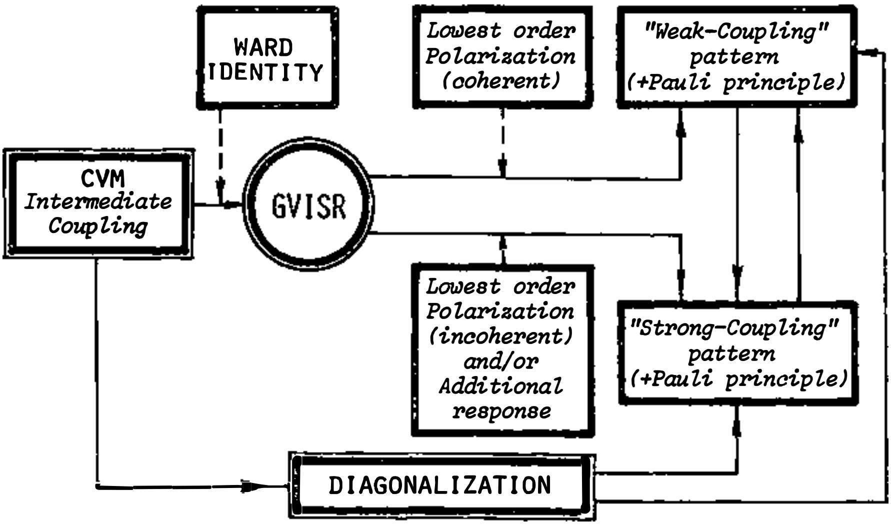

Fig. 1.

GVISR terms also provides useful quantitative estimates[9-18,22].

REFERENSES

1) L. Landau, *J. Phys. USSR.* 5 (1941) 71.

2) A. Bohr and B. R. Mottelson, *Mat. Fys. Medd.* 27 (1953) No 16.

3) G. Alaga, *Bull. Am. Phys. Soc.* 4 (1959) 359.

4) B. J. Raz, *Phys. Rev.* 114 (1959) 1116.

5) G. Alaga and G. Ialongo, *Nucl. Phys.* A97 (1967) 600, *Phys. Lett.* 22 (1966) 619.

6) N. Bijedić, *Phys. Lett.* 16 (1965) 47.

7) G. Alaga, F. Krmpotić and V. Lopac, *Phys. Lett.* 24B (1967) 537.

8) V. Lopac, *Nucl. Phys.* A155 (1970) 513.

9) V. Paar, *Phys. Lett.* 39B (1972) 466, 39B (1972) 587, 42B (1972) 8.

10) G. Alaga, *Rendiconti Scuola Internazionale,* Varenna 40 Corso 1967, p. 28; *Cargese lectures in theoretical physics,* 1968, p. 579; *Nuclear Structure lectures,* Alushta, JINR D-6465, Dubna, 1972, p. 288.

11) V. Paar, *Nucl. Phys.* A211 (1973) 29; *Z. Phys.* 271 (1974) 11; *Phys. Rev.* C11 (1975).

12) G. Alaga and V. Paar, to be published.

13) G. Alaga, *Proc. of Topical Conf. on Problems of Vibrational Nuclei,* Zagreb, 1974, eds. G. Alaga, V. Paar and L. Šips, *(North-Holland Publ. Co., Amsterdam)* 1975.

14) V. Paar, *Proc. of Extended Seminar on Nuclear Physics, ICTP,* Trieste 1973 (IAEA, Vienna), in print; *Proc. of Topical Conf. on Problems of Vibrational Nuclei,* Zagreb, 1974., eds. G. Alaga, V. Paar and L. Šips *(North-Holland Publ. Co., Amsterdam)* 1975.

15) V. Lopac, *Proc. of Topical Conf. on Porblems of Vibrational Nuclei,* Zagreb 1974., eds. G. Alaga, V. Paar and L. Šips *(North-Holland Publ. Co., Amsterdam)* 1975.

16) G. Alaga, V. Paar and V, Lopac, *Phys. Lett.* 43B (1973) 459.

17) G. Alaga, F. Krmpotić, V. Lopac, V. Paar and L. Šips, to be published.

18) V. Paar and B. K. S. Koene, to be published.

19) R. Béraud, I. Berkes, R. Harotunian, G. Marest, M. Meyer-Levy, R. Rougny, A. Troncy, A. Baudry and V. Lopac, *Phys. Rev.*. C4 (1971) 1829.

20) T. Fényes, I. Mahunka, Z. Matè, R. V. Jolos and V. Paar, *Nucl. Phys.,* in print.

21) V. Paar, Ch. Vieu and J. S. Dionisio, to be published.

22) V. Paar, to be published.